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U.S. ARMY AND DEPARTMENT OF DEFENSE EXPERIENCE WITH THE USE OF B20 AND OTHER BIODIESEL BLENDS

INTERIM REPORT
TFLRF No. 441

by
Steven R. Westbrook

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Luis A. Villahermosa
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD17-Task 2)

UNCLASSIFIED: Distribution Statement A. Approved for public release

May 2014

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Approved by:

Gary Bessee

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
05/20/2014

2. REPORT TYPE
Interim Report

3. DATES COVERED *(From - To)*
June 2011 – May 2014

4. TITLE AND SUBTITLE
U.S. Army and Department of Defense Experience with the Use of B20 and Other Biodiesel Blends

5a. CONTRACT NUMBER
W56HZV-09-C-0100

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Westbrook, Steven R.

5d. PROJECT NUMBER
SwRI 08.14734.17

5e. TASK NUMBER
WD 17

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®)
Southwest Research Institute®
P.O. Drawer 28510
San Antonio, TX 78228-0510

8. PERFORMING ORGANIZATION REPORT NUMBER
TFLRF No. 441

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army RDECOM
U.S. Army TARDEC
Force Projection Technologies
Warren, MI 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
UNCLASSIFIED: Dist A
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
As an early and wide-spread adopter of the use of biodiesel, the DoD has had a variety of experiences, both problems and successes. Problems have included poor biodiesel quality, oxidation stability, low-temperature operability, water removal, and microbial growth. Successes include reductions in petroleum diesel consumption and meeting EPAct requirements.

In general, the Department of Defense has been, and continues to be, a strong proponent of the use of alternative fuels such as biodiesel. In the case of biodiesel, there are restrictions against using it in tactical vehicles owing to increased potential for problems. However, the judicious use of biodiesel remains a component of the DoD's overall fuels policy and will likely be so for many years.

15. SUBJECT TERMS
biodiesel

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	65	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

This report summarizes Army and other DoD experience with the use of biodiesel blends, primarily B20. The Army has been studying the use of biodiesel as a blend component with petroleum diesel since the mid 1990's. The Air Force has become the largest single user of B20 within the Department of Defense. While the Navy prohibits the use of biodiesel in tactical vessels, the use of biodiesel in facilities applications has grown, including development of biodiesel production capabilities. The Coast Guard is exposed to biodiesel mainly as B5 blends with commercial diesel fuel.

As an early and wide-spread adopter of the use of biodiesel, the DoD has had a variety of experiences, both problems and successes. Problems have included poor biodiesel quality, oxidation stability, low-temperature operability, water removal, and microbial growth. Successes include reductions in petroleum diesel consumption and meeting EPAct requirements.

Some of the conclusions observations so far include:

1. Biodiesel should not be used in ships with water ballasting.
2. Fuel systems that utilize copper, such as copper fuel lines on some ships, may have problems with the use of biodiesel since copper is known to catalyze degradation of biodiesel.
3. The U.S. Navy currently does not allow biodiesel/biodiesel blends for shipboard use.
4. The Air Force uses primarily B20. They have experienced problems with biodiesel oxidation, low-temperature operability, water separation, microbial growth, and material compatibility.
5. They are working through various solutions to these issues and have measurable success in some areas.
6. Since the U.S. Coast Guard (USCG) routinely buys commercial diesel fuel, they are likely to receive B5 on a regular basis. USCG personnel are being reminded to maintain good fuel inventory management onboard ships. The USCG is also considering the use of fuel biocide to mitigate microbial growth problems.

7. Most experience reported to date, by all DOD organizations, supports the restriction against use of B20 in tactical equipment.
8. At Fort Leonard Wood, 66% of the vehicles run on alternative fuel.
9. Since the Clear and Bright test can be subjective, it is necessary to include a quantitative test, modified ASTM D6217.
10. Most commonly used biodiesel in the U.S. has been methyl esters of soybean oil which tends to have the highest amount of unsaturation, which can autoxidize to form acids, microparticulates and polymers.

In general, the Department of Defense has been, and continues to be, a strong proponent of the use of alternative fuels such as biodiesel. In the case of biodiesel, there are restrictions against using it in tactical vehicles owing to increased potential for problems. However, the judicious use of biodiesel remains a component of the DoD’s overall fuels policy and will likely be so for many years.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period June 2011 through May 2014 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative. Luis Villahermosa of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical and administrative support staff.

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ACRONYMS AND ABBREVIATIONS

AFV	Alternative fuel vehicle
APC	Army Petroleum Center
CID	Commercial Item Description
CONUS	Continental United States
CUCV	Commercial Utility Cargo Vehicle
DoD	Department of Defense
DOE	Department of Energy
ECRA	Energy Conservation and Reauthorization Act
EISA	Energy Independence and Security Act
EPAct	Energy Policy Act
ESTCP	Environmental Security Technology Certification Program
FLW	Fort Leonard Wood, Missouri
HEMTT	Heavy Expanded Mobility Tactical Truck
HMMWV	High Mobility Multipurpose Wheeled Vehicle
OCONUS	Outside Continental United States
POL	Petroleum, Oil, Lubricants
POMCUS	Pre-positioned Overseas Materiel Configured in Unit Sets
RFS	Renewable Fuels Standard
TARDEC	TACOM Automotive Research and Development Center

1.0 BACKGROUND

In 1992, the United States Congress enacted the Energy Policy Act (EPAct) requiring federal and state vehicle fleets to purchase alternative fueled vehicles (AFV). EPAct was amended in 1998 as the Energy Conservation and Reauthorization Act (ECRA) to include use of biodiesel as an option for meeting AFV requirements by purchasing and using either 450 gallons of biodiesel or 2250 gallons of B20 blend (80% petroleum diesel / 20% biodiesel). The Energy Policy Act of 2005, and the Energy Independence and Security Act (EISA) of 2007 (including the Renewable Fuels Standard, RFS and RFS2, 2010) also provided additional requirements for the production and use of biodiesel.

In the 20 years since EPAct, the Department of Defense has remained at the forefront of evaluation and use of biodiesel blends in diesel-powered vehicles, primarily 20% blends. As an early user of B20, the DoD encountered biodiesel with a wide range of quality, resulting in a wide range of experiences with the blend. This report is a summary of experiences that the DoD has had with the use of biodiesel blends.

1.1 HOW MILITARY TACTICAL/COMBAT FUEL USE AND NEEDS DIFFER FROM COMMERCIAL USE

There are a number of liquid fuels used in Army materiel. The fuels have been classified/termed as primary, alternate, or emergency fuels [1]. The Army has two very important documents that direct, control, and classify the fuels for use in military equipment. These are AR 70-12 (Fuels and Standardization Policy for Equipment Design, Operation, and Logistics Support) and DOD Directive Number 4140.25 (DOD Management Policy for Energy Commodities and Related Services). AR 70-12 implements DOD 4140.25. DOD 4140.25 indicates that “Primary fuel support for land-based air and ground forces in all theaters (overseas and CONUS) shall be accomplished using a single kerosene-based fuel, in order of precedence: JP-8, commercial jet fuel (with additive package), or commercial jet fuel (without additives), as approved by Combatant Commanders. Fuel support for ground forces may also be accomplished using commercially available diesel fuel when supplying jet fuel is not practicable or cost effective". It is further stated in AR 70-12 that "…all ground vehicle and equipment with compression-ignition and turbine engines will be designed to perform acceptably using kerosene-type turbine fuels such as JP-8 or JP-5, distillate fuels such as diesel fuel (CID A-A-52557)…." [2].

Following these documents, the U.S. Army conducted and completed a JP-8 conversion program for the tactical/combat fleet located in Continental United States (CONUS) and Outside CONUS (OCONUS) bases.

Therefore, any alternative fuels for the combat/tactical fleet must have properties that fit within the JP-8 requirements and be compatible with legacy and future systems. Non-tactical military and other federal fleets, such as trucks, buses, cars, etc. are considered potential users of alternative fuels. (See later section titled "alternative fuels and biodiesel exhaust emissions" for the DOE definition of alternative fuel.) Please note that alternate fuel is not the same as alternative fuel.

2.0 TRI-SERVICE POL USERS GROUP POSITION STATEMENT

The Tri-Service POL Users Group issued a position statement on the use of biodiesel in tactical vehicles and equipment. The group supported the prohibition of the use of biodiesel for tactical applications and does not support any proposed biodiesel tactical fleet demonstrations until all technology related concerns have been resolved. The text of the statement is located in Appendix A.

3.0 EPACT CREDIT

The U.S. Department of Energy published the final rule for the use of biodiesel to meet EPAct requirements in January 2001 [1]. The rule allowed fleets to use biodiesel to fulfill up to 50% of their alternative fuel vehicle (AFV) purchase requirements. Under the ruling, fleets could claim one biodiesel use credit for each 450-gallon purchase of B100. That is the equivalent of one AFV acquisition. In order to claim the credits, the fuel used must be at least B20 and used in vehicles weighing more than 8,500 pounds. Only the biodiesel portion of a blend could be used to calculate the 450 gallon requirement. That translated into a minimum use requirement of 2,250 gallons of B20 per vehicle, per year. No partial credits were allowed.

4.0 U.S. ARMY EXPERIENCE

Fort Leonard Wood, Missouri was the first U.S. Army installation to meet the requirements of the Clean Air Act of 1990 by fueling their vehicles with B20. The B20 use started in March 2003 [2]. Table 1 gives B20 usage at Fort Leonard Wood (FLW) for the first 4.5 years of usage. Through July 2007, the Fort reported no vehicle (including 427 tactical vehicles) problems as a result of using B20 [3]. During this same time period, the Fort was prepared for an increase in fuel filter replacement, but that did not happen.

Table 1. Fort Leonard Wood Annual B20 Usage for the First 4.5 Years of Use [4]

Fiscal Year	Volume, gallons
03 (January start)	76,891
04	134,778
05	178,731
06	223,250
07 (up to July)	188,474*
* FY07 already 8,000 gallons over FY06 usage for the same time period	

During a visit to Fort Leonard Wood in July, 2007, TARDEC personnel noted the following regarding the use of B20:

Conditions found at FLW TMP can be summarized as follows:

- Storage equipment was either new or less than 10 years old.
- All storage tanks were above ground tanks making inspections more practical.
- Implementation of TRAK (TRAK Engineering, Inc) keys that limited refueling only at the TMP refueling station and keyed to the particular alternative fuel used by the vehicle.
- High B20 fuel usage with deliveries twice a month.

- FLW has average temps between -9 °C to 32 °C (16 °F to 89 °F).
- A B20 sample taken in July 2007, as reported by APC (Appendix C), had a cloud point of -10 °C with winter products expected to have even lower cloud points.
- Supplier and producer of biodiesel are committed and implement procedures to ensure a good quality product is provided. This is demonstrated by the voluntary implementation of the BQ-9000 procedures.
- All tactical equipment was always under the direct control of the TMP and refueled only at the TMP station.
- The Fort Leonard Wood experience with B20 demonstrates the ability of tactical equipment to successfully use B20 with no problems; however, it should be noted that this statement is true for the conditions and parameters encountered at this location.

Based on the experiences at Fort Leonard Wood, the following recommendations were put forth:

- Use the experience of Fort Leonard Wood as reported here to develop guidance that other installations can follow.
- Guidance must consider that not all locations would receive the same support, commitment, and quality of biodiesel/blends as in Fort Leonard Wood.
- Guidance that allows installations to use biodiesel blend in tactical equipment should ensure, as much as possible, there are no adverse impact to equipment readiness, operability, or maintainability.
- Guidance should advise on the variety of biodiesel variants that are possible and that ultimately the user is responsible for ensuring equipment readiness and operability.
- Guidance and criteria must be developed to help commands determine which installations would be good candidates for using biodiesel fuel (B20) in tactical/military equipment.

In April 2000 Alfaro reported on the results of a vehicle test conducted at Yuma Proving Ground [5]. The following is taken from Alfaro's presentation of the results of the project.

- Evaluation performed on several ground tactical vehicles from March 1994 through March 1995.
- Testing done to compare vehicle performance on a 80/20 blend of JP-8/Biodiesel, neat JP-8, and neat DF-2.
    - Vehicles tested: Commercial Utility Cargo Vehicle (CUCV)
    - High Mobility Multipurpose Wheeled Vehicle (HMMWV)
    - M939A2 Series of 5-Ton Truck
    - Heavy Expanded Mobility Tactical Truck (HEMTT)
    - M915A2 Truck Tractor
    - Test conducted: engine exhaust smoke opacity measurements, vehicle acceleration, and paved drawbar pull
    - All of the vehicles tested were operating with DF-2 prior to the introduction of the biodiesel fuel blend.
- The Biodiesel Fuel Used in Evaluation:
    - 6,127 gallons of neat biodiesel were delivered for test and stored in 10,000 gallon above-ground storage tank.
    - Biodiesel fuel blend used was 20% biodiesel and 80% JP-8.
    - Biodiesel fuel blend was blended on site by simultaneously pumping 100 gallons of neat biodiesel and 400 gallons of neat JP-8 into a fuel pod.
    - Chemical analysis with IR Spectroscopy showed biodiesel fuel blend contained between 18.6 and 23.0 percent of neat biodiesel.
- Results
    - Engine exhaust smoke opacity measurements: All of the vehicles had a reduction in the snap idle opacity reading from 11 to 76 percent.
    - Vehicle acceleration: All of the vehicles showed a decline in acceleration using the biodiesel fuel blend compared to DF-2.
    - All of the vehicles showed no effect or an improvement in acceleration using the biodiesel fuel blend compared to JP-8.
    - Paved drawbar pull: All the vehicles tested, except the HEMTT, showed equal or increased pull force when operating with the biodiesel fuel blend versus neat JP-8.

- Maintenance Effects
    - During the endurance operation, some engines ran poorly after the biodiesel fuel blend was introduced into the fuel system.
    - The primary reason was plugged fuel filters.
    - Possible reasons for the plugged filters is the solvency effect of the biodiesel. This contributed to dirt deposits being dissolved and being trapped in filters.
    - The cleaning effect of the biodiesel caused fuel leaks because of dissolved deposits which were part of the sealing interface.
    - Four major fuel components (all fuel injection pumps) failed during testing. One failure (in a HMMWV) was attributed to lack of fuel in the pump (plugged filter)
    - Two fuel pumps (in CUCVs) required replacement due to fuel leakage. The reason is a combination of deterioration of internal seals (due to age) and biodiesel solvency effect.
    - No cause was found for the fourth failure (in a HMMWV).
    - The engine idle speed was low after the introduction of the biodiesel fuel blend and required adjustment for individual vehicles within all the vehicle types.
    - Vehicle types with high mileage before the test (such as HMMWVs) seemed to have more problems than vehicles with lower initial mileage (such as CUCVs and M923A2 trucks).
- In conclusion, it is safe to say that the biodiesel fuel blend enhanced the problems in the fuel systems due to the increase of the solvency of the fuel whenever the biodiesel was added to JP-8.

Over the period of 2000 to 2003, TARDEC published the results of an extensive study of the effects of biodiesel, blended into petroleum diesel, on key specification properties [6][7]. In this paper they reported that previous studies had identified the following potential problem areas:

- Low temperature properties
- Storage stability
- Low compatibility with copper
- Incompatibility with nitrile rubbers

- A potential to degrade some fuel filter media, resulting in media migration
- Altering the coalescing process for free water in water coalescers/separators.

Stavinoha and his co-workers also analyzed several biodiesels and biodiesel blends to evaluate the effects on fuel properties. That work led to the following observations:

- Biodiesels can have properties that exceed the limits imposed on diesel fuel according to ASTM D975. The concentration of biodiesel used in a final blend will ultimately determine the level of impact to the diesel fuel blend.
- The property that will be affected the most, and of greatest concern, is the cloud point. Biodiesels have a wide range of cloud points and their impact on the final blend must be carefully assessed. The results showed that for low-sulfur, grade No. 2, diesel fuel blends, the cloud point increased around 2 °C, however, for low-sulfur, grade No. 1, diesel blends, the cloud point increased up to 20 °C. This is a significant change that needs to be carefully controlled during winter operations. Investigation of other cold flow properties was outside the scope of this effort.
- No specific differences could be determined between the unused feedstock versus the used feedstocks used in the manufacture of the biodiesel from the samples analyzed in the study. It appears that used feedstocks are more likely to result in biodiesels with higher cloud points than unused feedstocks.
- The B20 samples tested in the study showed that biodiesel blends, even at this high concentration of biodiesel, can meet a number of diesel fuel properties as defined by ASTM D975; but, not the 90% recovered temperature limit (ASTM D86) of 288 °C for grade No. 1.
- Based on the results of the study, it was apparent that inclusion of B5 biodiesel blend using both petroleum diesel grades 1 and 2 could be transparent to the user if the biodiesel did not exceed 5 vol%.

As a result of this study, DoD released a commercial item description to cover biodiesel blends at 20 vol% [8].

5.0 OTHER DOD EXPERIENCE

Owing to its' position as the largest DoD user of diesel fuel in ground vehicles, the Army conducted much of the early work on the use of biodiesel blends in ground vehicles. However, the restriction against the use of biodiesel in tactical vehicles greatly limited the use of biodiesel throughout the entire Army vehicle fleet. At the same time, the other services were exploring the possible use of biodiesel to help meet EPAct requirements. Eventually, the U.S. Air Force (USAF), adopted a far more widespread use of biodiesel blends (primarily B20) in their ground vehicles and ultimately became the largest user of B20 in the Department of Defense, as shown in Figure 1 below. This usage pattern has continued to date.

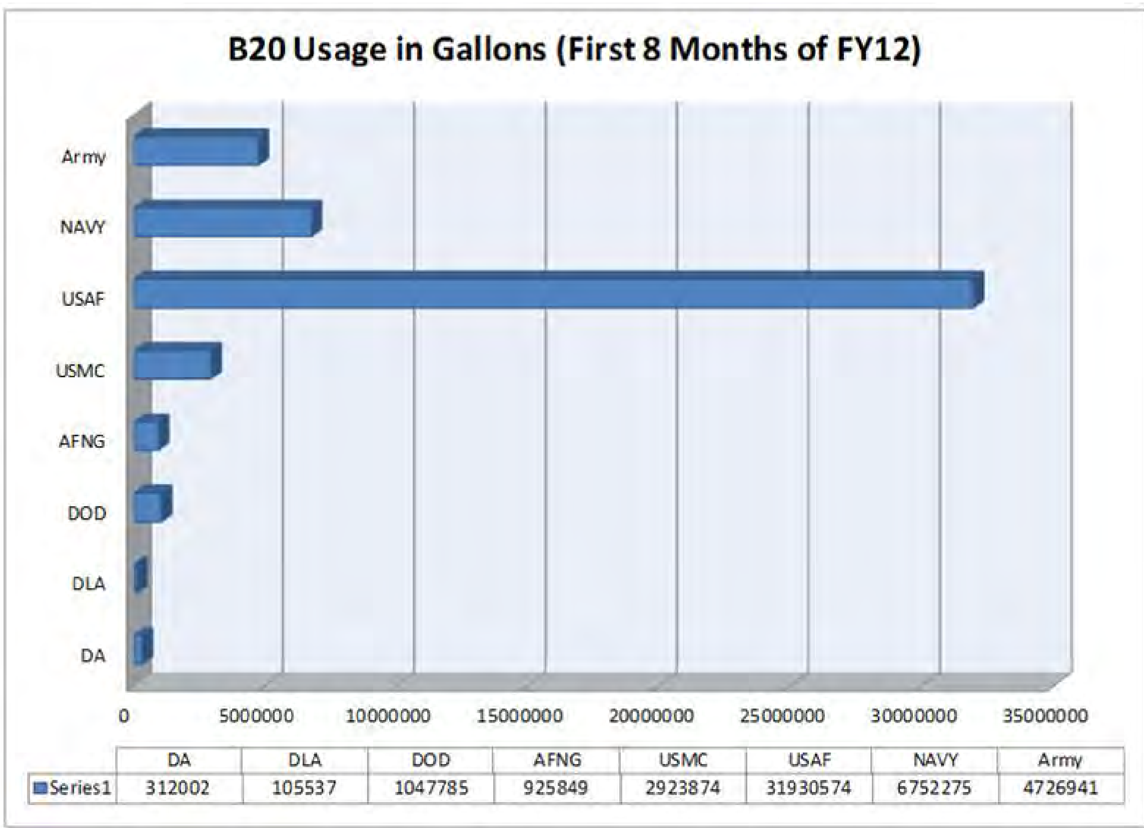


Figure 1. Department of Defense Usage of B20, By Service, for the First 8 Months of FY2012 (Source: DLA Energy)

This section covers experiences of other services with the use of biodiesel blends. They are grouped according to service.

5.1 AIR FORCE EXPERIENCE

In 2004, Young presented the results of a B20 study conducted at Vandenberg AFB: [9]

- The USAF Arbitrarily Established A Six-Month Shelf Life Requirement For B-20
- AF Space Command Began A B-20 Shelf Life Test At Vandenberg in Apr 03
- 7,800 Gallons Of B-20 Stored In A 20K Aboveground Tank Sitting Idle
- Samples Taken Monthly And Forwarded To Wright-Patterson Area Lab
- No Sample Failures Or Dramatic Chemistry Changes From Apr 03 - May 04
- Product Will Continue To Be Sampled Monthly Until There Is A Failure
- Based Upon The Vandenberg Data, The USAF Is Going To Extend The B-20 Shelf Life To 12 Months

The following is from a presentation made by Air Force personnel in 2010 [10]

- Suggested Vehicle Parts to Monitor
    - Fuel filter plugging

      –Mild filter plugging can prematurely activate emission regeneration cycle on newer vehicles

      –Severe filter plugging can damage fuel and injector pumps
    - Material incompatibility

      –Certain gasket materials are susceptible to B20 damage
    - Oxidized B20 damages several types of Viton (NREL 2009)

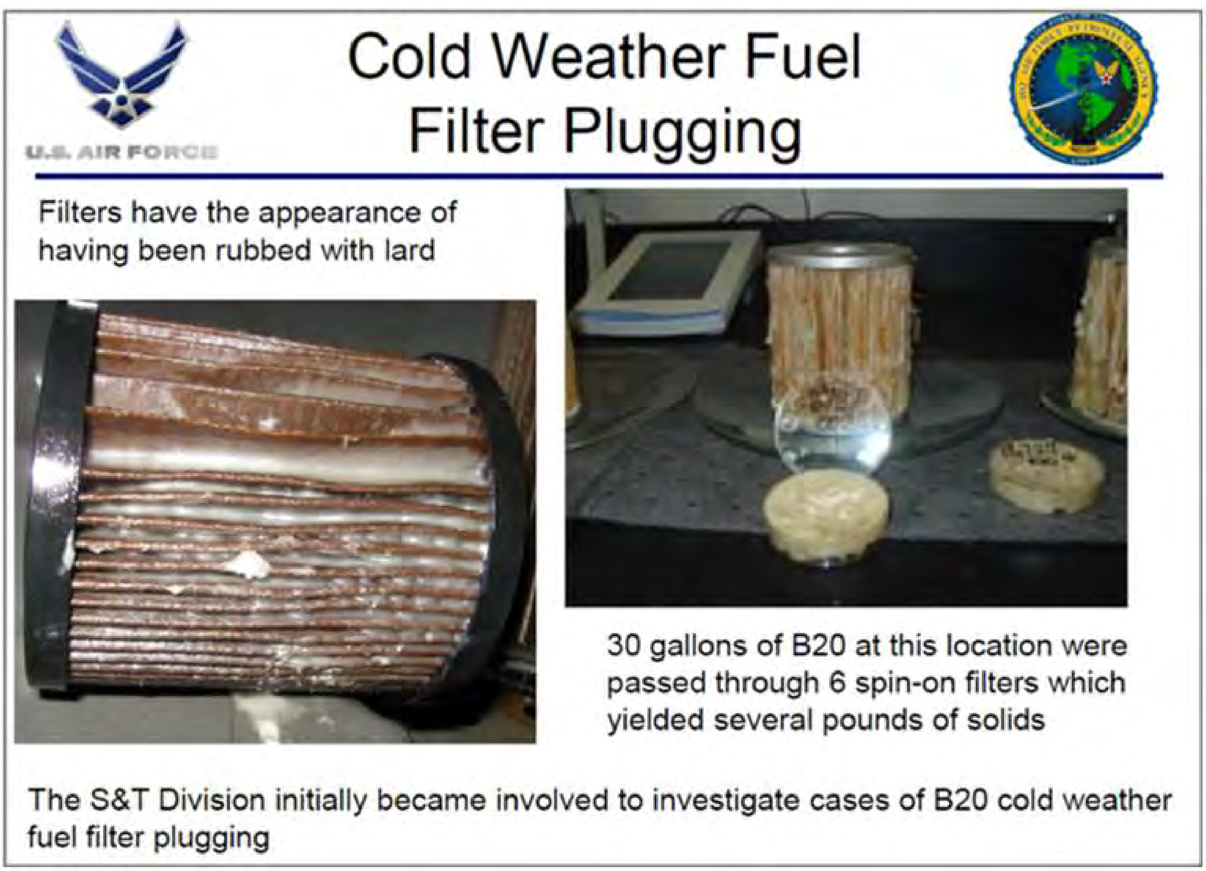
      –Copper fuel floats dissolved by B20's solvency

      –Fuel sending units losing screens
    - Fuel conditioning modules may contain sludge due to B20 thermal degradation (oxidation)

      –Hot fuel that doesn't enter the fuel injection system is re-circulated through the module

- Fuel Injectors (FI)
  - –FI replacement seems high
  - –Deposits in the common rail
- Fuel pumps and FI pumps
  - –Fuel filter plugging starves the pump
  - –Can be caused by the presence of solids in the fuel
- Exhaust Gas Recirculation (EGR) Valve problems
- Orange or brown solids in the vehicle fuel tanks
  - –Seen in warmer climates
  - –Testing indicates a degraded biodiesel (oxidized biodiesel)
- Turbocharger failures (oil and fuel lubricated)

U.S. Air Force experience is presented in the following slides:



Fuel Filter Plugging

U.S. AIR FORCE

- In October 2009 the AFPA directed the sampling of every B20 tank bottom with a Bacon Bomb Sampler
  - The Bases were instructed to submit any samples to the AFPA that were not clear & bright
  - The decision to sample was based upon an unusual tank bottom seen at an Air Force (AF) Base in the southern US during the winter of 2009
  - In all 19 bases submitted samples from 21 tanks
  - Additional samples followed once cold weather set in
  - Many bases with hazy tank bottoms experienced fuel filter plugging when colder weather arrived

Tank Bottom Sampling

U.S. AIR FORCE

Nozzle Sample

Bottom Sample

These samples were typical for Bases where fuel filter plugging occurred

U.S. AIR FORCE

Tank Bottom Analysis

- With the exception of several tanks that had microbial growth none of the hazy samples had excessive water
- The haziness was determined to have been caused by trace components in the B20 which were concentrating in the tank bottoms
  - Components not regulated by the current specifications
  - Some samples contained solids that dissolved when agitated
- Concentrated trace components are eventually issued into a vehicle when enough accumulates
- Fuel filter plugging occurs shortly after issue during cold weather

U.S. AIR FORCE

Chemical Analysis of the Hazy Tank Bottoms

- The following compounds were identified in the tank bottoms that are likely to exist as solids, and their melting points
  - Cholesterol (MP 299°F)
    - Indicative of an animal fat feedstock
    - Animal fat based biodiesel not approved for DoD contracts
  - Plant Sterols
    - Sitosterol (MP 279°F)
    - Campesterol (MP 315°F)
    - Stigmasterol (MP 338°F)
  - Glycerides
    - Monopalmitin (MP 167°F)
    - Monoolein (MP 97°F)
  - Tocopherol (MP 235°F), a biodiesel anti-oxidant
  - Long Chain Saturated FAME

U.S. AIR FORCE

Unusual FAME Find

- After numerous B20 problems at one location on the Gulf of Mexico the AFPA was able to identify this compound in their tank bottom
  - Docosahexaenoic acid methyl ester (C22:6) (MP -8°F)
    - Highly reactive compound, likely to break down quickly
      - May only have a storage life of 6-8 weeks
    - Most likely source – fish oil
    - Quality Assurance Representative reported fish odor in B100 tank
      - Human nose actually more sensitive than some instrumentation
    - Base experienced repeated microbial problems with this B20
    - Solids in the bottom of the bulk storage tank a reoccurring problem
    - High levels of cholesterol were also found indicating the use of an animal fat feedstock in violation of DoD contracts

U.S. AIR FORCE

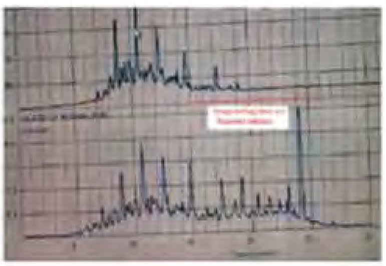
Fuel Filter Plugging Mitigation

- Last winter the AFPA directed the disposal of 8 B20 hazy tank bottoms
  - Several bases disposed of hazy tank bottoms assuming that the haze was due to water
  - Those Bases that reported fuel filter plugging typically had several hundred gallons of hazy fuel in their tank bottoms
  - Reports of fuel filter plugging dropped dramatically at these locations after disposing of the hazy tank bottoms
  - While the cases of fuel filter plugging were down last winter it was costly to dispose of these tank bottoms

Microbial Growth

U.S. AIR FORCE

- Biodiesel is easily metabolized by fungi and microbes
  - Several samples of B20 received contained no biodiesel as the fungi had preferentially metabolized it first
- Automatic Tank Gauging (ATG) can fail to detect water once growth is established
- B20 should not be stored in a tank with water management issues



Stability of Biodiesel

U.S. AIR FORCE

- The thermal and oxidative stability of biodiesel has been shown to cause solid formation in fuel tanks and vehicles
  - The Bobtails on the following slide each received a new fuel tank at the start of the ESTCP project about a year ago
  - The tank of the older Bobtail is already coated with an orange biodiesel breakdown product similar to the coating on the fuel sending unit below.
  - The solid is degraded biodiesel most likely caused by exposure to heat at an AF Base in a southern US location
  - Vehicle design plays a role as well

Vehicle Design Bobtails

- Fewer B20 maintenance issues, and occurrences of B20 tank solids have been reported with the newer Bobtails. Changes to vehicle design may play a role.
  - Fuel tank covered, less exposed to the sunshine/heat
  - Fuel cap more appropriate and robust
  - Due to recess, less chance of getting water/rain into the fuel tank during refueling

2007

1996

2009 NREL Biodiesel Handling and Use Guide 4th Ed. Appendix E

- The Air Force is trying to address material compatibility problems with elastomers and gaskets
- Table E-1 Elastomer Compatibility with Biodiesel
  - Could be leveraged by the maintenance community to identify elastomers that shouldn't be used and a suitable substitute
- Viton is a common elastomer used in FI O-rings
  - Viton A-401C and Viton F-605C incompatible w/oxidized B20
  - Viton GBL-S and Viton GF-S compatible with all biodiesel
  - Standard Viton: cure affects compatibility with oxidized biodiesel
- Other Elastomers adversely affected by biodiesel
  - Buna-N, Butadiene, Natural Rubber, Neoprene, 4 types of Nitrile, Polypropylene, Styrene-Butadiene,

5.2 NAVY EXPERIENCE

The Navy prohibits the use of biodiesel/biodiesel blends in Navy vessels. However, they have extensive experience with the use of biodiesel blends in facilities engineering (Naval Facilities Engineering Service Center (NFESC)) applications. The reports in this section are related to those applications.

NSFEC has long conducted work to develop sources of feedstock and capabilities for biodiesel production at Naval port facilities. According to a press release from Aug 11, 2009:

> Aug 11, 2009 PORT HUENEME, Calif., Aug. 11 /PRNewswire-FirstCall/ -- A collaborative effort by the U.S. Navy, Biodiesel Industries, Inc. and Aerojet successfully demonstrated methods to produce cleaner and more reliable sources of renewable fuels for military use. The system, named ARIES (Automated Real-time, Remote, Integrated Energy System), is a highly automated, portable biodiesel production unit that can be controlled from a remote location. These features ensure reliable process control and optimal production yields in a system that can be readily and widely deployed.

On 19 November 2003, Lynda Turner made a presentation at the Naval Fuels & Lubricants IPT Quality Day. Part of that presentation was a discussion of Navy efforts regarding use of biodiesel at that time:

- As Mandated in EO 13101/13149 the Navy position is to encourage use of biodiesel for non-tactical use only where feasible
- Naval IPT position : BIODIESEL SHALL NOT BE USED IN TACTICAL VEHICLES
- Naval Guidelines: –Only at locations where consumption is within 6 months
- Must have infrastructure already in place
- All Navy procurement requirements must be passed through NOLSC-DC (NPO) first
- Naval activities are highly encouraged to procure through DESC
- Navy supports DESC Clause 16.27
- Product not meeting C 16.27 is not permitted in DLA-owned tanks

- Determination of tank cleaning needs contained in Naval Message
- Naval Base Ventura County, Port Hueneme, CA Naval Facilities Engineering Service Center/Biodiesel Industries, Inc. developed a modular biodiesel processing unit Uses cooking oil/esterification process
- Current usage: NBVC: 20,000 gallons/yr
    - Channel Islands National Park: 20,000 gallons/yr
    - Ventura County: 20,000 gallons/yr
- Project with Arizona Tour Boats (Pearl Harbor) using B100
- Coast Guard Academy biodiesel trial (B20)

A 2008 report gave the results of Navy investigations of blends of synthetic fuel and biofuels [11]. The conclusions from the report cautioned about blending biofuels and synthetic fuels:

> "The blending of various fuels must be done with great caution. The results from this study showed that this particular FT fuel was not compatible with soy-derived biofuels. Even at low concentrations, 5%, and elevated temperatures and pressures, the biodiesel appeared insoluble when blended with FT and an FT petroleum middle distillate blend. This insolubility produced a large yield of sediments in the ASTM storage stability test. This insolubility means that all of the FT blends with biofuel could potentially lead to mechanical issues with a ships' propulsion system and most certainly could not be stored and be used as diesel fuels for combat operations.
>
> **This has significant relevance to the Navy as 5% biodiesel is entering the commercial market, and the certification of FT fuels and FT fuel blends with petroleum middle distillate fuel for military applications is underway."**

In another report from the NFESC, [12] Holden reported on the results of engine emissions testing with biodiesel blends, at Naval Facilities:

> “This report summarizes the results of a 3-year project lead by the Naval Facilities Engineering Service Center (NFESC) to obtain emissions factors (i.e. tailpipe air pollution emissions data) from 10 types of Department of Defense (DoD) operated diesel powered engines. Emissions data was obtained from 8 vehicles, primarily buses and trucks, and 2 portable generators. All testing was performed with the engines installed in the vehicles/portable equipment.
>
> Emissions factors were determined for the engines fueled with various blends/types of biodiesel as well as a baseline fuel, either California Air Resources Board (CARB) certified Ultra Low Sulfur Diesel (USLD) (15-ppm sulfur maximum) or JP-8. CARB USLD was used since it will be required within California for on-road vehicles starting in June 2006. Biodiesel blends from 20% to 70% were tested along with 100% biodiesel. For the blended biodiesel testing, the biodiesel was mixed with USLD. Although several blends were tested, the project focused on B20 (20% biodiesel) blends, since this is the primary blend of biodiesel used in military vehicles.
>
> Testing performed on B20 fuels identified three significant results (1) There were no consistent trends over all engines tested, (2) There were no statistically significant emissions differences found between biodiesel fuels manufactured from yellow grease or soy bean oil feedstocks, and (3) An extensive statistical analyses indicated no statistically significant differences in Hydrocarbon (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx) or Particulate Matter (PM) emissions between a B20 biodiesel manufactured at Naval Base Ventura County from yellow grease and CARB ULSD petroleum diesel.

> The results from this project are significantly different than those previously reported by the Environmental Protection Agency (EPA). Of particular interest is the fact that for actual DoD fleet diesel engines, there was no statistically significant increase in NOx emissions."

5.3 COAST GUARD EXPERIENCE

The Coast Guard, CG, has a policy of not using biodiesel blends in their vessels. But the CG uses a large amount of commercially available diesel fuel which may contain 5% biodiesel. As such, the CG has some experience with biodiesel, B5, in their vessels.

5.3.1 USCG Cutter SENECA

The US Coast Guard Cutter (USCGC) SENECA (270-foot Medium Endurance Cutter (WMEC 906)) received MGO with differing volume-percentages of biodiesel from Boston, Massachusetts during 2012. The table below illustrates the lifting dates, quantity, and biodiesel volume-percent received. The SENECA was in port from June 2012 through mid-August 2012. The biodiesel problems developed in early September 2012 and the cutter was still experiencing problems up to six months after receiving the biodiesel fuel. The severity of the problems fluctuated depending on the type of fuel received onboard the cutter (petroleum middle distillate/diesel fuel (MGO) vs. biodiesel fuel). If MGO was received, then the fuel filters' usage rate and the fuel oil purifier (FOP) cleaning rate trended towards their normal periodicity, however if biodiesel was received, then both fuel filter use rate and FOP cleaning rate were substantially increased.

Note: MGO procured for the US military (USN, USCG, MSC, etc) meets the ISO 8217 Grade DMA specification, along with additional US military marine requirements (i.e. sulfur, biodiesel, etc). The US only has the middle distillate/diesel fuel specification, ASTM D 975, for use on-road and off-road, which includes the marine sector. Therefore, the diesel fuel supplied in the US will essentially be only ASTM D 975 fuel, which has a sulfur maximum of 15 ppm or 0.0015 wt% (ultra low sulfur diesel (ULSD)). filter usage and the FOP cleaning rate dramatically increased as described below.

Lifting Date	Quantity (Gallons)	Biodiesel vol% (EN 14078)
5/11/2012	21000	3.48
6/6/2012	15005	3.01
8/22/2012	20750	2.75
9/8/2012	27000	0.27
9/26/2012	26000	0.27
10/18/2012	24500	2.31

1. Excessive fuel filter replacement rate (for both the main diesel engines and the diesel engine-powered generators) was due to the solvency effects of biodiesel. When the filters were visually inspected by cutter personnel, gelatinous particulate matter as well as other material debris was found.

   A. Main Diesel Engines (ALCO 251F18MS):

   - Each main diesel engine has a Nugent duplex strainer followed by a Facet coalescer.
   - Fuel filter replacement rate with MGO – approximately every month (550 hours).
   - Fuel filter replacement rate with biodiesel fuel – every three days (50-60 hours).

   B. Diesel Engine-Powered Generators (Caterpillar D398B (TA)):

   - Each diesel engine-powered generator has a Racor duplex filter coalescer followed by an engine-mounted Caterpillar 7N8853 filter assembly.
   - Fuel filter replacement rate with MGO – approximately every 2-3 weeks (250-350 hours).
   - Fuel filter replacement rate with biodiesel fuel – every three days (50-60 hours).

2. The fuel coalescer filters required replacement at more frequent intervals with biodiesel fuel. (The fuel transfer system contains a SAREX TP-2833 particle/water removing fuel filter.)

   A. Fuel coalescer filter replacement rate with MGO – If the coalescer filters were used as the primary means to recirculate and transfer fuel, then normally the filters were changed every 2 weeks (300 hours).

   B. Fuel coalescer filter changes with biodiesel fuel – The coalescer filters had to be used more frequently, therefore the filters required replacement every 2-3 days (60-70 hours).

3. The FOP (Alfa Laval TP-2701) required cleaning at more frequent intervals with biodiesel fuel.

   A. FOP cleaning intervals with MGO – approximately every 720 hours. The FOP is normally run all day every day and cleaned twice per patrol (approximately 60 days).

   B. FOP cleaning intervals with biodiesel fuel – approximately every 160 hours. The FOP was run all day every day and required cleaning once per week.

4. The type of material debris found in the FOP when cleaned was different with biodiesel fuel.

   A. FOP debris with MGO – normally there is a slimy layer of sticky black residue. The FOP disks can be wiped clean with a rag and petroleum middle distillate/diesel fuel.

   B. FOP debris with biodiesel fuel – The layer of black sludge was much thicker with biodiesel, however the FOP disks were cleaned the same way as with MGO.

5. The SENECA was unable to consistently achieve a bright fuel sample from the FOP. Fuel from the bottom of the storage tanks after passing through the FOP would also be clear but not bright. The fuel's color was very dark, even though the MGO loaded onboard was clear/yellow/red dyed.

In summary, the SENECA received two biodiesel fuel lifts before the cutter's dock-side period from June through mid-August 2012 and four biodiesel fuel lifts after. The biodiesel problems developed in early September 2012 and the cutter was still experiencing problems months after receiving the biodiesel fuel. Since October 18, 2012, the SENECA has not received any further biodiesel fuel. The early biodiesel fuel lifts from May through August have been burned completely and only a few fuel tanks on the SENECA contain the fuel from the September refuelings. As of early March 2013 only one tank has a mixture of the October biodiesel fuel with recently lifted, biodiesel-free MGO fuel. While the fuel filters, filter coalescers, and FOP usage has gotten better, as of this writing (mid-March 2013) the cutter has not yet returned to its normal FOP cleaning/fuel filter/coalescer replacement intervals.

5.3.2 USCG Cutter Alder

The following is taken from a trip report by DLA Energy and US Coast Guard personnel. The trip was Feb 28 to Mar 4, 2011 to investigate a problem with fuel quality.

The United States Coast Guard Cutter (USCGC) Alder, stationed at Lake Superior, Duluth, MN is a 225 class (225-foot) icebreaker buoy tender (ICBT). The vessels' main propulsion is two Caterpillar 3608, eight cylinder diesel powerplants that generate 3,100 horsepower each. The vessels' electrical load is sustained by two Caterpillar 3508, 450 kW diesel generators. The vessel also has a Caterpillar 3406, 285 kW backup generator with a dedicated service tank. Typically, the USCGC Alder consumptions about 230 gallons per hour with both main engines and one main generator operating at full capacity.

The primary fuel consumed by the USCGC Alder is dyed marine gas oil (MGO). Typically, this is the fuel used by most, if not all USCG vessels, However, in this case, the MGO contains 5% biodiesel (B5). The State of Minnesota mandates the use of B5 in all marine vessels operating in the waters of the State of Minnesota. It should be noted, that the USCGC Alder had not experienced any major fuel system problems until the inclusion of B5 in MGO. The Fuel system on board the vessel is comprised of nine fuel storage tanks, three fuel service tanks having a combined capacity of 77k gallons. The vessel also has two centrifugal purifiers, numerous strainers and filter/coalescers. The fuel system (Figure 2) has the capability of redirecting fuel to and from all tankage as necessary to meet operational requirements. The Alfa Laval HHPX-405 centrifugal purifiers (Figure 3) remove extraneous contaminates from the fuel as product is being transferred from the storage tanks to the services tanks.

Figure 2. Fuel Management/handling System

Figure 3. Centrifugal Purifier

Strainers and filter/coalescers (Figure 4) are incorporated into each of the main propulsion systems and electrical generators on-board the vessel. However, the vessel does not have the capability to re-circulate fuel within a tank. Typically, fuel stocks on-board the vessel cannot fall below 60 percent due to operational readiness requirements. It should be noted that since there are separate seawater ballast tanks on-board, the fuel system does not have a dedicated stripping pump. Meaning, fuel tanks can be stripped, but only via the transfer pump. Operationally, tanks are not stripped unless water contamination is detected during weekly soundings.

Figure 4. RACOR Generator filter/coalescers

DISCUSSION

The primary purpose of this visit was to investigate the extent and cause of micro-biological growth occurring in the vessels' fuel system. A vessel tour along with a review of the vessels blueprints helped narrow the investigation. This included vessel docking and refueling procedures along with the local climate conditions in and around Lake Superior. As stated earlier, the vessel resides on Lake Superior, the winter conditions there are extreme. Typically, Lake Superior remains locked in ice from mid December thru Late March. The atmospheric temperatures during that period range from -25 °F to +30 °F. Understanding these conditions and the effects on the USCGC Alder would prove pivotal in determining the root cause of the micro-biological growth with the fuel system.

During the tour, it was noted that the temperatures inside the generator and engine rooms were quite warm even though the vessel was static. The term static means that only minimal power generation is required while the vessel resides at the dock. In this case both main engines and generators were static, yet the temperature in the engine room was 74 °F. This would seem quite normal if it wasn’t for the fact that engine room sits below the waterline where the temperatures are just above freezing. Further examination of the vessel’s blueprints revealed that the engine room and the fuel service tanks share the same bulkhead (common wall), thus concluding that condensation may be the primary cause of the microbiological growth. To prove this theory, the service tanks would need to be inspected.

To facilitate the verification process, service tanks 3-61-1 and 3-62-2 were scheduled for cleaning and inspection. On Mar 1st, the access cover was removed from tank 3-61-1. The initial visual inspection revealed very little, since the tank was 92% of maximum capacity. However, once the majority of fuel was removed, it became apparent just how extensive the microbiological growth within the tank had become. Visually, the tank bottom was covered in a liquid carpet of ooze approximately four inches thick (Figure 5). The adjacent walls were covered in similar ooze up to the original fuel level to a thickness of about 3/4" of an inch (Figure 6). The area above the fuel line exhibited numerous vertical condensation pathways. The roof of the tank (floor of the engine room) was spotted with rust-sized water droplets. Concluding that condensation must have been developing in all areas within tank above the fuel level. For future analysis, samples were taken of the micro-biological growth found in the tank. However, before shipping the samples to PAX River, a close-up evaluation was conducted. Visual inspection (Figure 7) shows the consistency of the micro-biological growth. Note its mass and texture. It was awe inspiring. So the big question is…what environmental conditions are necessary to amass this much micro-biological growth?

Figure 5. Note the depth and thickness of the growth

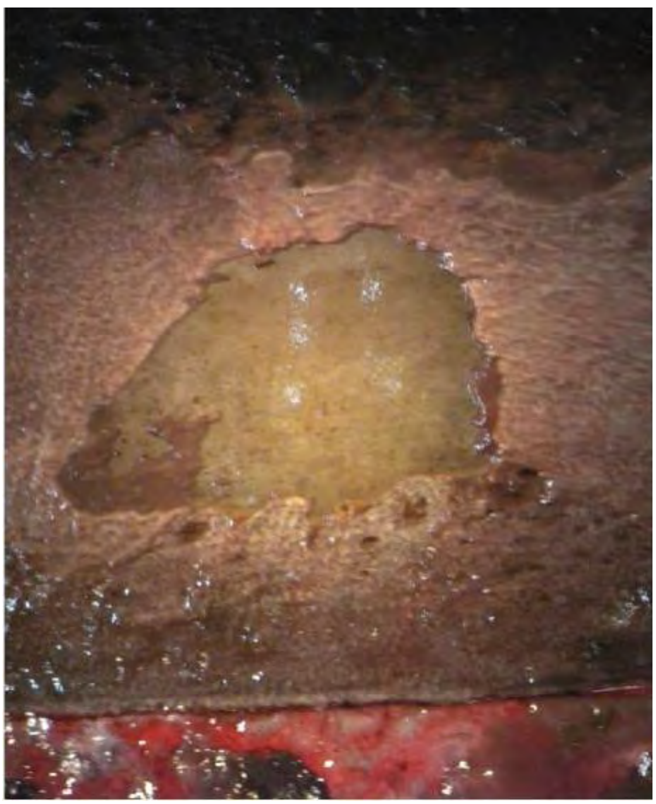


Figure 6. Shows the wall growth just before it sheared off

Figure 7. Micro-biological growth sample from Tank 3-61-1

To determine the ideal growing environment, an investigator does not need to look any further than the USCGC Alder residing in Lake Superior. There are two main contributing factors to the growth occurring in the service tanks. First, is the average water temperature for Lake Superior and second, are the engine room temperatures. As part of the investigation, a non-contact infrared thermal sensor was used to determine the internal tank temperatures prior to entering tank 3-61-1. Temperatures were taken in one foot increments from the top of the fuel to the roof of the tank. Starting with a fuel temperature of 44 °F, the incremental temperature increased by approximately 2-3 °F/ft, with the internal roof temperature measuring 63 °F. The bulkhead temperature of the adjacent engine room wall measured 68 °F. While the average engine room temperature was recorded at 72 °F. So the temperature Δ of the internal tank wall adjacent to the engine room and the engine room temperature is 4 °F (remember the compartments share the same bulkhead). Consequently, the current temperature Δ of the fuel and the adjacent engine room bulkhead measured 24 °F. However, this temperature differential still does not suggest that there is enough condensation being generated to amass the quantity of microbiological growth witnessed.

To substantiate the claim that the micro-biological growth is due to condensation, service tank 3-62-2 was also opened, fuel removed, and visual inspected. This tank is also adjacent to the engine room and shares a common bulkhead. The visual inspection revealed that the tank condition mirrored what was seen in tank 3-61-1 (Figure 8). With proof in hand, it can be concluded that tank 3-61-1 and 3-62-2 share similar environmental conditions with regards to condensation buildup and micro-biological growth.

Figure 8. Tank 3-62-2

The next step was to review the engine room heat stress data logs for the past year. These logs are used to record the daily engine room temperatures during normal operations. Unbeknownst, these logs provided a unique insight into the cause for the condensation. The recorded engine room temperatures ranged from 96 °F to 115 °F. Based on the recorded temperatures, the temperature Δ of the fuel and the engine room bulkheads adjacent to both service tanks could be as high as 70 °F. Under those conditions, the development of large quantities of condensation is more than plausible.

The final step into proving that condensation was the root cause was to review the inline sample data for the USCGC Alder. None of the results over the past year indicated that any of the fuel deliveries were laced with water. Also, as stated earlier, all fuel transferred from the storage tanks to the service tanks are processed through the centrifugal purifiers, thus removing any potential residual water and contaminates.

With the root cause determined, why wasn't any water detected during the weekly soundings? A review of the sounding logs confirmed that the process was being conducted correctly and IAW USCG regulations. However, an internal inspection of the service tanks revealed that the datum plates located directly below the sounding tubes are elevated approximately 2 inches off the floor. Therefore, unless the water level was greater than 2 inches, sounding the tanks for water would be an exercise in futility.

To determine the extent of the micro-biological growth, the strainers and filter/coalescers were removed, inspected and replaced for both powerplants, and generator system. The strainers showed micro-biological growth similar to that witnessed in the service tanks but on a much smaller scale (Figure 9). However, the filters looked somewhat normal, with only minor residual growth occurring within the pleats of the filter elements (Figure 10). Similar results were noted on all the remaining strainers and filters.

Figure 9. Strainer pulled from Generator #2

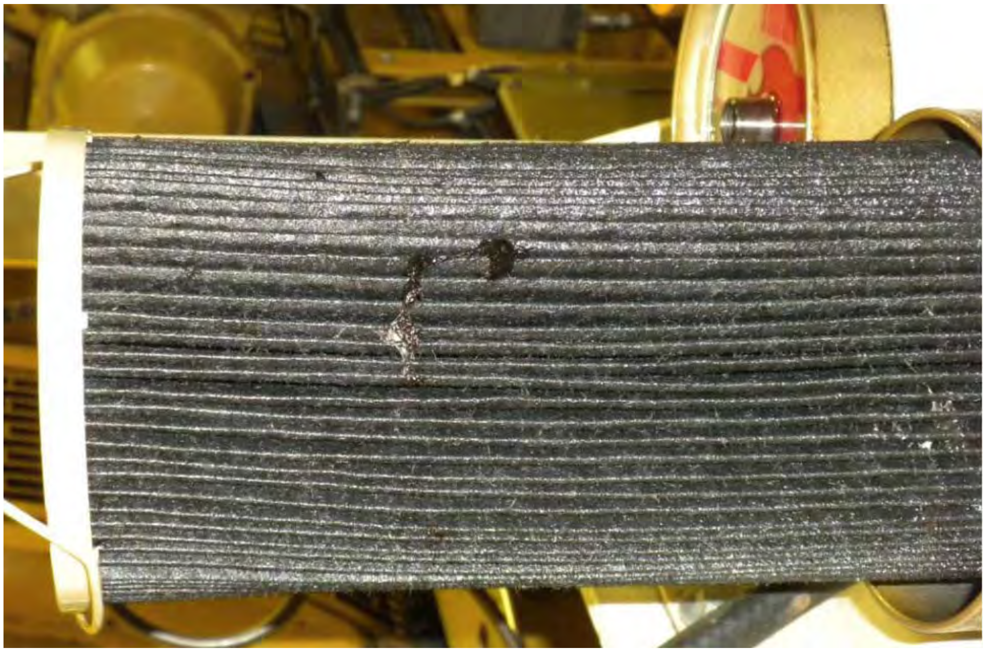


Figure 10. Filter removed from Racor canister unit of Generator #1

With the extent of the problem defined, a contractor was hired to clean the service tanks. Product was removed, the confined space rendered gas-free, walls scraped, sludge removed, floors squeegeed, the entire compartment power-washed, and ragged dried. Two other vessel tanks were inspected for cleanliness and potential micro-biological growth. Both the overflow tank (3-54-0) and emergency generator tank showed little signs of contamination. Neither of these tanks is adjacent to the engine room, indicating that the climate conditions in these spaces are far less dramatic and are not as conducive to micro-biological growth.

During the investigation, an ancillary problem arose that may exacerbate the existing problems associated with the micro-biological growth issue. It was revealed that the fuel in tanks 3-48-0, 3-48-1, and 3-48-2 were not being rotated. Fuel in those tanks may reside there for as long as a year before being rotated. These tanks, which reside amid-ship, are used for ballast. Though this situation is not ideal from a fuel prospective, it had very little impact when the fuel was free of biodiesel. However, now that the vessel is receiving B5, the potential for micro-biological growth greatly increases. To compound the problem, bio-diesel, regardless of the feedstocks used, is hydrophilic, meaning it readily absorbs water. Combine this with a known product shelf life of 4-6 months, and you have a recipe that could lead to mission failure.

CONCLUSION

Based on the findings, the USCGC Alder was given three (3) recommendations. First, personnel in positions of responsibility along with maintenance personnel need to have a better understanding of the fuels they receive and its interaction with their equipment. Second, is to improve the overall fuel management on-board the vessel. Fuel that is rotated on a consistent basis tends to remain on-spec longer, since it is periodically being blended with newer/fresher product. Third, is the introduction of a biocide. Because of the unique conditions witnessed on-board the USCGC Alder, the vessel has no way of managing the condensation issue. The introduction of a biocide will help mitigate the micro-biological issue in the long term. However, in the short term, the problem may get worse before it gets better. The biocide will kill the living organisms; however, the remains of the dead organisms will continue to clog the strainers and filters until the problem has cycled.

As a sidebar, DLA Energy, along with the USCG representatives, met with numerous suppliers in the area to determine the availability of bio-diesel free (B0) MGO. It was concluded that B0 is available in the area, but only via truck delivery. Currently, all pier-side refueling that takes place at Murray Oil contains B5, due to the Minnesota State bio-diesel statute. However, Murray Oil is looking into the possibility of making B0 available at the pier for vessels that are exempt from the State statute. Currently, the USCGC Alder is fully operational and conducting icebreaking operations to reopen the shipping lanes on Lake Superior.

5.4 OTHER

A presentation given in 2011 [13] summarized the results of a multi-vehicle, multi-site evaluation of B20. The objective of the project was to demonstrate and validate the use of B20 in non-deployed ground tactical vehicles and equipment by addressing users concerns regarding:

- Stability of the biodiesel
- Accelerated deterioration during high temperature storage
- Vehicle operation and fuel properties in low temperatures
- Water affinity and microbial degradation
- Material compatibility and solvency

Findings from the study include:

- Fuel stability was still a major concern (Moody AFB) – Orange deposits were found in some vehicles
- There was a lack of maintenance data available in some cases
- The number of test vehicles was small

6.0 SUMMARY

This report summarizes Army and other DoD experience with the use of biodiesel blends, primarily B20. The Army has been studying the use of biodiesel as a blend component with petroleum diesel since the mid 1990's. The Air Force has become the largest single user of B20 within the Department of Defense. While the Navy prohibits the use of biodiesel in tactical vessels, the use of biodiesel in facilities applications has grown, including development of biodiesel production capabilities. The Coast Guard is exposed to biodiesel mainly as B5 blends with commercial diesel fuel.

As an early and wide-spread adopter of the use of biodiesel, the DoD has had a variety of experiences, both problems and successes. Problems have included poor biodiesel quality, oxidation stability, low-temperature operability, water removal, and microbial growth. Successes include reductions in petroleum diesel consumption and meeting EPAct requirements.

In general, the Department of Defense has been, and continues to be, a strong proponent of the use of alternative fuels such as biodiesel. In the case of biodiesel, there are restrictions against using it in tactical vehicles owing to increased potential for problems. However, the judicious use of biodiesel remains a component of the DoD's overall fuels policy and will likely be so for many years.

7.0 BIBLIOGRAPHY

1. Alfaro, E.S., "Biodiesel Suppliers Survey", U.S. Army Tank-Automotive Research, Development and Engineering Center, Warren, MI, December 2001.
    - Survey conducted on known manufacturers/suppliers of neat biodiesel (B100).
    - 60% of companies interviewed supplied recycled biodiesel.
    - All suppliers could supply B20 or ship B100 and contract with a local fuel blender.
    - TARDEC published the B20 CID, A-A-59693 on 7 September 2001.
2. Villahermosa, L.A., "Biodiesel," October 2011.
    - Biodiesel seems to impact more the cloud point of low temp diesel fuels.
    - B100/20 showed equivalent results when using D2500 or D5773, or using GF/F or Nylon filters.
    - Biodiesel shows variability in oxidation stability more with virgin products than recycled.
    - Data indicates biodiesel behaves like a Newtonian fluid & exhibit same property response as expected from diesel fuel.
    - Data indicates recycled product makes as good biodiesel as from virgin materials.
3. "Biofuels Help Green the Department of Defense." Clean Cities Now 10.2 (May 2006): 2-3.
    - At Fort Leonard Wood 66% of the vehicles run on alternative fuel.
    - From the 2004 & 2005 data, FLW used more than 154,000 gallons of E85 and 255,000 gallons of B20.
4. "Biodiesel Offers Fleets a Better Alternative to Petroleum Diesel." Clean Cities Technical Assistance Fact Sheet. May 2001
    - TACOM approved a Purchase Description (PD) for the procurement of B20 to pave the way for biodiesel purchases.
    - B20 can be used in all non-tactical vehicles and with further research may be used throughout the military.
    - DESC issues a biodiesel solicitation in an effort to streamline the process through which federal agencies buy B20 for use in diesel vehicles and equipment.

5. "Diesel Fuel, Biodiesel Blend (B20)," A-A59693A. January 2004.
    - B20 requirements.
    - B20 not been approved for use in Army combat and tactical vehicles and equipment at this time.
6. Alfaro, E., "Particulate Contamination Requirement for the B20 Commercial Item Description (CID)," U.S. Army TACOM-TARDEC, Warren, MI, August 2001.
    - Looking at incorporating an ASTM D6217 particulate contamination requirement into the soon-to-be-issued B20 CID.
    - 20 B20 samples were analyzed. Two of the samples had particulate levels of 14+ mg/L, and had passed the Clear and Bright requirement.
    - Since the Clear and Bright test can be subjective, it is necessary to include a quantitative test, modified ASTM D6217.
7. Alfaro, E.S., Dobbs, Jr., H.H., Stavinoha, L.L., Villahermosa, L.A., "Alternative Fuels: Development of a Biodiesel B20 Purchase Description," 2000-01-3428, 2000.
    - A purchase description for B20 biodiesel has been written, but places restrictions on B20.
    - Need to determine more accurately the storage life, but using 6 months from delivery for now.
    - Fuels that have a TAN greater than 0.25mg KOH/g are not recommended for use.
    - A demonstration fleet test utilizing the DOD PD B20 for fuel procurement would be useful for converting the PD B20 to a CID for B20.
    - Want to test fuel filters to force the use of tighter filters having much higher retention characteristics for very small particles.
    - Previous evaluations of biodiesel and biodiesel blends have identified potential problem areas: low temperature properties, storage stability, low compatibility with copper, incompatibility with nitrile rubber, degrade some filter media resulting in media migration and alter coalescing process for free water in water coalesce/ separators.

8. The Guidon, March 2003
   - Fort Leonard Wood Army post is the first Army installation to meet the requirements of the Clean Air Act of 1990, offering E85 and B20.
9. Handy, G., “Biodiesel Use in DoD Tactical Ground Vehicles,” JSEM Conference, May 2007.
   - Tactical vehicles exempt due to Tri-Service concerns: fuel stability, potential increase in vehicle maintenance and compatibility with existing infrastructure.
   - A Joint Test Protocol (JTP) was put in place with all services, DLA and NASA to evaluate biodiesel use in tactical vehicles.
   - Will evaluate fuel stability, vehicle performance and maintenance conditions.
10. Villahermosa, L.A., “Fort Leonard Wood Biodiesel B20 Use in Tactical Equipment,” TARDEC Letter Report, ~2007.
    - FLW has been using B20 for approximately 5 years with no fuel associated problems reported in any of the 427 tactical vehicles.
    - FLW experience was limited to tactical equipment that was regularly used and operated with a high fuel turn-over, both at the 12K storage tanks and vehicle cells.
    - Storage and distribution equipment was either new or less than 10 years old. Fuel was delivered at least twice a month, minimizing fuel aging.
    - Visits to Jefferson City Oil Co, NBB and Mid-America Biofuels showed they were committed to manufacturing and supplying good quality product.
11. Stavinoha, L.L., Alfaro, E.S., Tebbey, J.M., Villahermosa, L.A., “Biodiesel and Biodiesel Blend Properties Related to Epact Use,” International Conference on Stability and Handling of Liquid Fuels, Steamboat Springs, CO, September 2003.
    - Most commonly used biodiesel in US has been methyl esters of soybean oil which tends to have the highest amount of unsaturation, which can autoxidize to form acids, microparticulates and polymers.
    - Field tests have been uneventful. Minor repairable fuel system leaks and fuel filter plugging attributed to cleanup of dirty fuel systems.
    - NBB estimates over 40 fleets are operating on B20.

- Due to B20's solvency property which could potentially dissolve filter binders, resins and cause swelling of cellulosic fibers, evaluation of elastomers and fuel filters should be considered along with qualification procedures for approving fuel filters.
- Characterization data on B100 blends in Warren, MI:
    i. Cloud point is affected the most. For LS 1-D blends, cloud point increased to 20 °C.
    ii. It appears that used feedstock results in a higher cloud point than unused feedstock.
    iii. Recommended to include a B20 blend specification in ASTM D975 to ensure product meets the needs of the equipment, including seasonal cold weather changes.

12. Brigadier General Lloyd T. Waterman, Department of Army, Office of the Deputy Chief of Staff, G-4 Memorandum, July 25, 2003

- Approval to use Biodiesel fuel in non-deployable tactical schoolhouse vehicles at Fort Leonard Wood, Missouri for one year.

13. Bax, K.G., Motor Transport Officer, Directorate of Logisitics, Fort Leonard Wood, MO, 2006.

- 66% of fleet using alternative fuel.
- In 2003 received permission to test biodiesel in the pool of 312 non-deployable, school house tactical vehicles.
- Even during extreme cold temperatures the test HMMWVs started and operated equal to and sometimes better than HMMWVs operating on regular diesel.
- Had to switch back and forth between B20 and regular diesel and no issues arose.
- Currently use B20 in 425 diesel burning tactical vehicles that are used in the Military Police and Chemical Schools Consolidated Equipment Pool. Vehicles range from light HMMWV to 5-ton trucks.

14. Stavinoha, L.L., "Considerations Related to the Use of FTD/Biodiesel in Military Diesel Ground Equipment," November 2004.

- 2 main pros for using Biodiesel: receive AFV EPACT credit and lower dependence on petroleum crude oil, and potential lower than ultra low sulfur designation of FTD B20.
- Cons to using biodiesel:
    i. Low temp properties, storage stability, low compatibility with copper, incompatibility with some nitrile rubber, filter/coalescer degradation, initial more frequent vehicle filter replacement, shortening of oil change interval, clear coat paint damage due to fill spill/wetting
    ii. EMA/FIE OEM concerns related to biodiesel purity and use of concentrations greater than 5% in equipment not specifically designed to use higher concentrations of biodiesel.

15. Villahermosa, L., “TARDEC Alternative Fuels Program for Dr. Kamely,” April 27, 2006
    - Unresolved issues with biodiesel:
        i. Stability – degrades in a short amount of time. Leads to formation of acids and polymers that can cause corrosion filter plugging and high temp deposit formation.
        ii. High and low temp properties – instability is accelerated at high temp and higher cloud points and pour points is poor cold weather properties.
        iii. Water affinity – forms emulsions with water accelerating fuel filter plugging and microbial contamination.
        iv. Material compatibility with certain elastomers, plastics and metals.
        v. Solvency – increased filter replacement.
        vi. Need additional storage tanks and handling equipment to segregate.
    - Limited research in biodiesel will be performed at TARDEC to evaluate cold flow improver additives and stability additives.
16. Alfaro, E.S., “Biodiesel Fuel Evaluation for the U.S. Army Tactical Wheeled Vehicles at Yuma Proving Grounds,” U.S. Army TACOM, April 18, 2000.
    - Testing done to compare vehicle performance on a 80/20 blend of JP-8/Biodiesel, neat JP-8 and neat DF-2.
    - All vehicles had a reduction in snap idle opacity reading from 11 – 76%

- All vehicles showed a decline in acceleration compared to DF-2, and no effect or an improvement compared to JP-8.
- All vehicles, except HEMTT, showed equal or increased pull force when operating compared to JP-8.
- During endurance operation, some engines ran poorly due to plugged fuel filters. Also caused fuel leaks due to dissolved deposits which were part of the sealing interface.
- Engine idle speed was low and required adjustments.
- Vehicles with higher mileage before the test had more problems than vehicles with lower initial mileage.

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    - Discusses ascent of petroleum fuels in twentieth century and the social, political and economic issues related to petroleum fuel in terms of U.S. national security vulnerabilities.
    - A literature review is provided of the history of biodiesel research beginning in the 1970’s.
    - Review of the U.S. Army TECOM Biodiesel Experiment. Vehicles were measured with DF-2 and JP-8 fuel versus biodiesel blended.
        i. Compared to DF-2, reduced opacity reading, indicating a reduction of solid particulate matter in the exhaust, up to 76% reduction initially.
        ii. Improved acceleration compared to JP-8. Acceleration was lower than DF-2.
        iii. Improved draw bar capabilities versus JP-8, and decreased compared to DF-2.
        iv. During an endurance operation, the frequency and type of faults experienced did not strike TECOM as extraordinary.

- A quantity analysis was performed and found that the amount of biodiesel necessary to displace 20% of the U.S. Army's JP-8 requirement in CONUS is 15% of the biodiesel produced in the U.S. in 2007.

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APPENDIX A
TRI-SERVICE POL USERS GROUP
POSITION STATEMENT

TRI-SERVICE POL USERS GROUP

Subject: **Use of B20 in Tactical Vehicles and Equipment**

1. Attached is the Tri-Service Petroleum, Oils and Lubricants Users Group (TRIPOL) position on the use of B20 in tactical vehicles and equipment. The TRIPOL supports the current prohibition of the use of B20 for tactical applications and does not support any proposed B20 tactical fleet demonstrations until all technology related concerns have been resolved.

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COL Carmen Goyette, USAF
Commander, AFPA

TRI-SERVICE POL USERS GROUP

Issue: Use of B20 in Tactical Vehicles and Equipment

Background: The Tri-Service Petroleum, Oil, and Lubricants Users Group (TRIPOL) is comprised of tactical POL subject matter experts (SMEs) from each Service. The chartered mission of the TRIPOL is to coordinate and harmonize individual Service weapon system POL requirements, specifications, policies, research efforts and their applications to ensure optimal weapon system operational readiness, supportability, sustainability, affordability and interoperability. Due to the heightened interest in the use of alternative fuels, the TRIPOL reviewed the Services' current policies for B20 use in tactical or Service-specific applications as well as available field data when equipment was exposed to biodiesel blends. B20 is defined as a fuel blend consisting of 80 volume % petroleum-derived diesel fuel and 20 volume % biodiesel. Biodiesel is further defined as Fatty Acid Methyl Esters (FAME) derived from animal or plant fat. Blends of up to B5 (95% diesel, 5% FAME) are currently permitted in commercial diesel fuel specifications.

Discussion: The TRIPOL recognizes and strongly supports both the Alternative Fuels and Greening of the Government initiatives. However, the implementation of alternative fuels, like B20, in the tactical fleet cannot be considered without identifying and resolving the issues that affect military mission and readiness. All the Services currently prohibit the use of B20 in tactical applications and provide guidelines for using biodiesel (or blends higher than 5% biodiesel content) for other applications. These policies or guidelines were developed based on the collective analysis that B20 and related technologies (additives, etc.) are premature for military applications. There are many critical issues that arise when using B20 in the tactical fleet that are not typically factors when used in commercial or non-tactical fleets. These issues include (expanded discussion in Attachment #1) fuel stability, low/high temperature properties, maintenance related requirements (such as water affinity, material compatibility, and solvency), logistics, storage facilities, etc. These critical issues and their technical challenges must be addressed and resolved before fleet demonstrations or implementation can be supported by the TRIPOL. Failure to do this properly will place the weapon system and operator at an unnecessary level of risk and increase maintenance or facilities costs due to remediation efforts. Tactical vehicles must be capable of deployment on a moment's notice and be able to perform mission critical requirements without encountering additional fuel-related maintenance and related risks. The Services also rely on supplementary equipment that is used to support the tactical equipment, so it needs to be ensured that their reliable operation is maintained. The use of B20 in tactical vehicles and support equipment severely jeopardizes this requirement. If these vehicles or equipment are exposed to B20, they will require increased maintenance efforts to remove B20 from the system because of its diminished environmental tolerance, increased maintenance costs, potential generation of additional waste, and delays in deployment. The increased maintenance and risk associated with diminished performance and reduced temperature tolerance would dramatically compromise operational readiness, which the single fuel on the battlefield has provided.

The TRIPOL recommends that, if DoD wants to continue to investigate the potential use of biodiesel in tactical/military service vehicles, the way forward would be to concentrate on the removal of the technical roadblocks followed by a fleet demonstration at a later time.

Position: The TRIPOL supports the current prohibition of the use of B20 for tactical applications and the following of the Service-specific guidelines provided, and does not support any B20 tactical fleet demonstrations until all technology-related concerns are resolved.

Attachment #1

Stability

B20 is far more susceptible to storage instability (oxidation) than is petroleum middle distillate fuels (F-76, JP-5, and JP-8). Oxidation and deterioration of the fuel leads to the formation of acids and polymers that can cause corrosion, filter plugging, and high temperature deposit formation. At this time there is no guarantee that the fuel delivered is either a stable product or that it will always be used in a timely manner (particularly true in tactical fleet). An unstable fuel will adversely impact vessel or vehicle performance once oxidation/deterioration products are present in the fuel. B20 can begin to degrade in a relatively short time-frame (matter of weeks or months), therefore it affects the ability of tactical equipment to be stored short term (i.e., travel time for combat mission) or long term (i.e., long duration vehicle storage, Pre-positioning of Materiel Configured in Unit Sets (POMCUS) or pre-positioned in ships or at military installations). Although the B20 specification (ASTM D7467) does contain a fuel stability requirement, it is insufficient to prevent fuel degradation when B20 is stored for both short and long periods of time. In addition, evaluations are needed to evaluate the effectiveness of stability additives being developed for biodiesel and ensure they are compatible with other fuels and traditional additives to which the tactical fleet will be exposed.

High Temperature Properties

B20 instability is accelerated by high ambient temperatures, which may cause it to degrade in a matter of weeks (or months). This stability issue means that B20 has a much higher potential to deteriorate than diesel fuel or JP-8 thus creating deposits and potentially plugging filters/fuel lines, etc.

Low Temperature Properties

B20 has poor cold-weather properties (higher cloud points and pour points) when compared to petroleum middle distillate fuels. Biodiesel in JP-8 or diesel fuel adversely affect the low temperature properties of the base fuel by increasing the cloud point of diesel fuel by a minimum of 2-3 degrees Celsius and the freezing point of JP-8 by a minimum of 20 degrees Celsius. This will adversely impact operations and readiness for lower temperature operations.

Water Affinity

In the presence of water, a heavy, milky emulsion will form causing hydrolysis of the ester and subsequently forming acids. These acids will lead to increased corrosion and increased maintenance in fuel systems containing steel, zinc, and aluminum. In addition, B20 is an excellent medium for the promotion of microbial growth, which may cause fuel system corrosion and accelerated fuel filter plugging. It is much more difficult to remediate these problems in tactical vehicles than in commercial vehicles and the repercussions are much more severe in tactical vehicles when it happens.

Material Compatibility

B20 will interact adversely with certain elastomers, plastics, and metals, which will affect the materials' physical properties and may lead to operational failure and/or increased maintenance.

Solvency

B20 has a "solvency" effect by cleaning existing fuel system deposits. Intermittent use of biodiesel may cause an increase in filter replacements.

Other Issues

B20 "Controlled Use"

Military tactical vehicles located CONUS and OCONUS are often required to change locations both seasonally and geographically at a moments notice to fulfill mission requirements. As a result, restricting B20 use to specific geographical sites or climates would be impossible considering tactical vehicles would be required to deploy at a moments notice regardless of environmental conditions.

Additional Fuel Tank/Handling Equipment

Additional storage fuel tanks and handling equipment will be necessary to segregate JP-8 from B20, due to the aforementioned innate properties of biodiesel. B20 fuel tanks (storage and vehicle tanks) would require increase maintenance to ensure microbial contamination is not present.